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FINAL TECHNICAL REPORT

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In Support of

SCALING THEORIES OF HYDROLOGY, HYDRAULICS AND GEOMETRY OF
RIVER NETWORKS

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An Overview

Understanding the dynamics of surface flows and land forms is a very important piece in the broad context of understanding how the land surface and the atmosphere interact. As the spatial scale of a basin increases, various hydrologic processes in the river basin, be it river runoff and floods or evapotranspiration through soil moisture, are strongly influenced by the two "boundary conditions". The first is the space-time variability in precipitation from the atmosphere and the second is the spatial variability in land forms including soils and vegetation. These two boundary conditions hold the key towards a broad understanding of land-atmosphere interactions, which range from the dynamics of regional climatic variability, for example through soil moisture, to the dynamics of natural hazards such as floods.

Our NASA/NSF joint grant was concerned with three different topics, i.e., precipitation, floods, and channel networks. A common theme underlying our research in all of the three categories was to identify scale ranges over which the hypothesis of *Scaling invariance in space* can be formulated and tested. Scaling invariance can be interpreted to mean that the dominant features of the system remain invariant as the size or the scale of the system changes. We made fundamental advances on several different fronts in this goal. Some of the milestones that we have achieved can be summarized as follows:

Space-time Rainfall

Most of our work on this topic focused on the mathematical development of the statistical theory of random cascades (Holley and Waymire, 1992; Waymire and Williams, 1994, 1995) and on testing the extent to which this theory describes multiscaling in the spatial variability of rainfall across a broad range of scales (Gupta and Waymire, 1993; Over and Gupta, 1994). One of the key difficulties in testing this theory arises from the fact that it is "non-ergodic", which means that spatial averages can not be equated to ensemble averages. This basic issue has not been widely appreciated in the literature. Most of our research in the context of rainfall was aimed at testing the structure of rainfall fields in a manner which recognizes the non-ergodic behavior of cascades. In addition, Tom Over is writing his Ph.D. dissertation on the applications of the cascade theory to rainfall.

The theory of cascades has its origins in the statistical theory of turbulence. Physical ideas involving structure functions and scaling originated in this theory. Two

papers on the application of the cascade theory to turbulence were published by Peckham and Waymire (1992) and by She and Waymire (1995).

Spatial structure of Floods

The current approaches to regional analysis of floods has been either data intensive based on regressions, or purely statistical, or based on the statistical-dynamics of rainfall-runoff. These three approaches have remained essentially disjoint from one another. Our research focused on exploring if the ideas of scaling invariance can furnish a framework which can unify flood dynamics, statistics and data. This new direction of research on floods seems very promising, and is beginning to provide unexpected new insights. The key papers on this topic are by Gupta and Dawdy (1994), Gupta, Mesa and Dawdy (1994), and Gupta and Dawdy (1995).

River Networks

The third topic was concerned with understanding the presence of scaling invariance in land forms and river networks across a broad range of scales. Scott Peckham finished his Ph.D. dissertation on this topic, and exciting and unexpected new results were obtained by him. This includes, (1) development of an elaborate software tool kit called RiverTools to automate analysis of DEM data sets, (2) development of notions of dynamic similarity and self-similarity based on a rigorous derivations of the momentum conservation equations governing the flow of water out of large basins, (3) a unified theory of self-similar trees which explains a large number of empirical findings for river networks. The last piece of research is published in Peckham (1995).

In addition, Maxwell (1995) and Zhang (1995) also completed their dissertations in this general area. Maxwell developed an approach to compute the streams of arbitrary orders that occur in a self-similar network as well as some methods for computing large network asymptotics. Zhang computed the width function for certain self-similar networks for comparison to the average width function of Shreve's classic random model the width function is basin scale hydrograph in the sense that one computes the probability that water randomly injected will reach the outlet in time t based on the network topology. As such this is a basic problem in the prediction from ungauged basins. Zhang's results further confirm the self-similar properties of the expected random model and provide techniques for continued study of this important problem for other self-similar networks. Several papers on river networks are currently being written-up.

Refereed Papers/ Ph.D. Theses Produced by the Research Grants

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